A LUNAR REGOLITH CHARACTERIZATION KIT (LRoCK).

J. B. Johnson[1], G. S. Mungas[2], K. Zacny[3], D. G. Albert[4], B. Banerdt[2], M. Buehler[5], R. C. Elphic[6] J. Lambert[2], M. Sturm[1], and K. Johnson[2] , [1]Institute of Northern Engineering, University of Alaska, PO Box 755910, Fairbanks, Alaska 99775, ffjbj1@uaf.edu, corresponding author; [2]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91009, Greg.Mungas@jpl.nasa.gov, JPL corresponding author; [3]Honeybee Robotics, 460 West, 34th Str. New York, New York 10001, zacny@honeybeerobotics.com; [4]USACE-ERDC-CRREL, 72 Lyme Road, Hanover, NH 03755, Donald.G.Albert@us.army.mil; [5]Decagon Devices, Inc., Pullman, WA 99163, mgbuehler@earthlink.net; [6]Planetary Systems Branch, NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035, richard.c.elphic@nasa.gov.

Introduction: The Lunar Regolith Characterization Kit (LRoCK) project is a concept study to define a semi-autonomous instrument package for use by astronauts during future human lunar sortie missions. LRoCK will provide measurements of the surface topography and the near-surface compositional, physical, and structural characteristics of lunar geology and regolith (Table 1).

The LRoCK integrated suite of surface and subsurface geophysics instrument package is intended to be emplaced by astronauts and set to operate autonomously while astronauts undertake other tasks. This allows for flexible and rapid characterization of a sortie landing site region. Subsurface instruments are deployed by using either a reciprocating impact drill or penetrometer, or a complementary coring drill for specialized applications. The near-surface core drill will provide Earth-return rock and soil samples for analysis. LRoCK tools and instruments have previous development heritage with relatively low mass and power requirements (Table 2).

Measurement Objective and Goals: The objective of the LRoCK is to provide a science measurement package to characterize the lunar surface and the compositional, physical, and structural heterogeneity and diversity of the lunar regolith in the region of sortie sites. The characterization uses *in situ* measurements and analysis of regolith cores returned to Earth.

Specific measurement goals include: (a) Measuring the in situ mineralogy (including the presence of volatiles), the strength, thermal properties, heat flux, and density (as a function of depth) for the upper 1.5 m of regolith at several locations around a Sortie site. (b) Extending the measurements from the upper 1 to 1.5 m of regolith to 10s of m in depth using active seismic methods. (c) Obtaining core samples of regolith (rock and soil [including volatiles]) for terrestrial analysis. (d) Determining the surface topography and three-dimensional location of sortie site measurements in order to link these to surface features. (e) Extended seismic and heat flux measurements that continue after the end of the sortie mission using deployed sensors. These can be incorporated into a separate global or regional network.

Table 1. LRoCK instrument suite.

Tools/ Instrument	Purpose
Drill/ penetrometer:	Determine soil strength & deploy subsurface instruments to a depth of 1.5 m.
Core Drills (soil coring and hand rock coring)	1. Obtain soil core samples up to 3 m deep in 1-m segments (sealed to retain volatiles), 2. Obtain rock cores,
Neutron probe	Determine abundance of hydrogen and other minerals [1].
Thermal Probe	Measure soil thermal properties and geothermal heat flux.
Gamma Ray Spectrometer	Measure bulk density & atomic number of soil minerals [1].
Electric Properties Probe	Detect ice/water or titanates; determine stratigraphy and regolith density [2].
Raman Probe	1. Determine bulk regolith mineralogy and soil chemistry with fiber optic probe in drill (at 1mm scale) 2. Differentiate rock mineralogy and core chemistry at the 1-10 micron scale with fiber optic coupled to CHAMP (see below).
Seismic Profiler:	Determine regolith stratigraphy, elastic properties, strength, and density regionally and help determine lunar interior structure and composition as part of a global seismic network.
CHAMP (Camera, Handlens, And Microscope Probe) Stereo camera with coupled Raman Probe	1. Determine 360° regional surface topography around sortie site. 2. Characterize soil and rock morphology from cm to micron scale. With Raman Probe, provide high resolution microscopic maps/stats of regolith and rock chemistry/ mineralogy investigations.

Table 2. LRoCK Instrument Systems Summary

Tool / Instrument	Mass (kg)	Volume (cmxcmxcm)	Power (W)
LRoCK Autonomous Instrument Suite			
Penetrometer	< 25	30x20x15	<200
Support stand		TBD	N/A
Neutron Gamma Ray Spectrometer (NGRS)	1.5	Drill Probe: 68.6 x 2.9 cm	3
		Electronics: NA	
Thermal Probe (TP)	< 0.5	Sensors: 0.5 x 0.5x0.5	< 1
		Electronics	
Electric Properties Probe (EPP)	< 0.2	Sensors:	< 1
		Electronics	
Raman Probe (RP)	< 1.5	Integrated Probe head <1 x1 x10	< 15
		Spectrometer: 30x30x30	
Seismic Profiler (SP)	< 1.5	Sensors:	< 1
		Electronics	
TOTAL	**<31**		
LRoCK Astronaut Instrument / Tools			
CHAMP	<1.0	10x15x40	< 5
Hand Coring Drill	<5	30x15x10	<100
TOTAL	**<6**		

Significance of LRoCK Measurements: During Apollo missions astronauts used a variety of tools and instruments to determine the makeup and properties of the lunar surface. Although analysis of data from these missions indicates a general similarity of regional and global regolith characteristics there is still a need to provide future astronauts with the tools and instruments to characterize specific sites of interest. For example, potential Outpost or other high-value sites need to be characterized for evaluation and planning purposes. Establishing a number of well-characterized sites where local regolith properties are known can facilitate analysis of global measurements (e.g., geophysics, mineralogy, stratigraphy). Characterizing polar regions that have yet to be visited [3] or other sites will improve the quality of existing lunar data [4].

Trade Studies to Fill Knowledge Gaps: Trade studies are being conducted to determine LRoCK tool and instrument capabilities and limitations. These will be used to define the final LRoCK instrument suite and define how the LRoCK science suitcase can be used most effectively during lunar sortie missions (Table 3).

Table 3. LRoCK instrument trade studies.

Tools/ Instrument	Trade Study Goals
Reciprocating impact drill/ penetrometer:	Define performance limits. Determine instrument integration requirements.
Core Drills	Determine cutter type and geometries. Determine core capture methods.
Neutron probe	Determine fit to drill geometry.
Thermal Probe	Determine mechanical insertion methods and limits. Determine operational parameters accuracy in lunar conditions.
Gamma Ray Spectrometer	Determine fit and operation scenario.
Electric Properties Probe	Characterize the effect of gap between drill and regolith.
Raman Probe	Optimize laser wavelength. Minimize fluorescence influences. Define laser spot size and focus. Select analysis scenarios.
Seismic Profiler:	Define details of seismic network components. Define deployment, operation and analysis details.
CHAMP	Investigate adding a second fixed focus infinity camera for stereo imaging of the LROCK investigation site. Investigate combine CHAMP/Raman spectrometer performance using lunar simulant.

References: [1] R. C. Elphic et al. (2008) *Astrobiology* (in press). [2] M.G. Buehler et al. (2007) IEEEAC paper #1375, IEEE Aerospace Conference (March 2007). [3] Committee on the Scientific Context for Exploration of the Moon (2007) National Research Council, National Academies Press, ISBN: 0-309-10920-5, http://www.nap.edu/catalog/11954.html. [4] Lucey, P. et al. (2006) *Reviews in Mineralogy & Geochemistry, 60.*

Acknowledgement: This work is supported by the NASA Science Mission Directorate, Planetary Science Division and Decagon Devices, Inc.